Chapter 3[3]
Regional Input-Output Analysis for OECD-Europe

3.1 Introduction

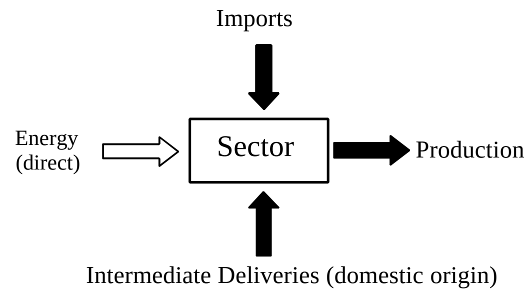

Figure 3.1: Schematic overview of the sector's input and output in terms of energy. The white arrow represents the direct input of energy and the black arrows represent flows of goods and services in terms of energy.

As mentioned in chapter 2, input-output energy analysis is used to compute the initial energy flows in OECD-Europe. Not only do these energy flows comprise direct energy use (*e.g.* the use of coal, oil products, gas and electricity) but also indirect energy use: energy required for the production of the goods and services purchased to be used in that sector. Figure 3.1[4] indicates that the energy content for the total production in a sector is equal to the combined energy content of goods and services purchased and of the energy directly used. This total is referred to as the embodied energy content for the total production of that sector (*cf.* chapter 2). *Embodied energy intensities* (expressed in MJ/US$) are often used to calculate the total energy content of deliveries from one sector to another as the embodied energy intensity of a sector equals the total amount of energy (direct as well as indirect) required to produce one unit of economic output in that sector. Input-output analysis (IO) appears to be an appropriate method for computing embodied energy intensities (denoted by EEI) because IO provides a systematic and all-inclusive framework in which indirect energy use is taken into account [Costanza, 1986]. This methodology has been outlined in several studies [Bullard and Herendeen, 1975; Costanza, 1986; Proops, 1988; Nieuwlaar, 1988; Wilting, 1996].

Ideally, imports should be included in the embodied energy intensities. They are, however, frequently neglected (*e.g.* [Nieuwlaar, 1988; Gowdy and Miller, 1991; Common and Salma, 1992; Hetherington, 1994]) because the data required to

[3] This chapter is based on [Battjes *et al.*, 1998; Battjes and Noorman,1998]

[4] Note that figure 3.1 is similar to figure 2.1

calculate the energy value of these imports are generally not available for most exporting countries. Naturally, this problem does not concern a sector's exports as these exports are part of the total production in that sector and thus, by definition, included in the calculations of that production.

In addressing the energy content of imports, the energy intensities of the imported products are often assumed to be similar that of domestically produced goods and services [Office of Technology Assessment, 1990; Wilting, 1996; Wyckoff and Roop, 1994; Noorman, 1995]. This assumption may introduce errors in the calculations as energy intensities vary from country to country. Different countries have different economic structures and levels of technology. This chapter addresses the impact of these differences in assessing the EEI of a sector's output or more particular on the EEI of imports. Differences in the electricity generating systems form a striking example. In countries such as France and Belgium, the generation of electricity depends heavily on nuclear energy, whereas in Norway most electricity is generated in hydro electric installations. As mentioned in section 2.6.4, in OECD-Europe, the fossil ERE-value of electricity ranges from about 0 for Iceland to 3.5 for Greece [OECD, 1991a-b]. In Iceland, all electricity is generated in hydro or geothermal plants, while in Greece electricity is mostly generated from the combustion of lignite. To illustrate that differences in national energy intensities exist, the energy intensities are compared at a sectoral level for a number of countries. But first a general overview is presented in what way the energy intensities are computed.

3.1.1 General Methodology of Determining Energy Intensities with IO-analysis

As mentioned before, input-output analysis is used to compute embodied energy intensities. The general concepts of the input-output methodology are described in this section.

Let X_i denote the total production of a sector and let Y_i denote the final demand of products originating from sector i. Final demand includes final consumption, changes in stocks, gross fixed capital formation as well as exports. Let z_{ij} denote the intermediate deliveries from sector i to sector j. If for each sector, total production equals the sum of intermediate output and final demand, one obtains the following equation:

$$\forall\, i;\ X_i = Y_i + \textstyle\sum_j z_{ij} \qquad (3.1)$$

Note that column totals ($\sum_i z_{ij}$) of the Z-matrix represent the total domestic inputs (or costs) of goods and services in that sector. From the Z-matrix, a matrix of input coefficients can be constructed which represents the domestic costs incurred per unit output. The matrix of input coefficients, denoted by A, is computed by dividing each industrial input by the total production[5].

Let I be the $n \times n$ identity matrix. From equation (3.1), it follows that:

$$X = (I - A)^{-1} * Y \qquad (3.2)$$

In this equation, $(I - A)^{-1}$ is referred to as the Leontief inverse and determines the direct and indirect inputs of a final demand.

The Leontief inverse is frequently used to compute the embodied energy intensities (denoted by ϵ) [Bullard and Herendeen, 1975; Miller and Blair, 1985; Peet, 1991; Wilting,1996]. If one assumes that energy is conserved in the production of goods and services (*i.e.* the energy content by the total production of a sector is equal to adding up the energy contents of its domestic intermediate inputs and imports, and its direct energy use), the following equation can be obtained for each sector:

$$\forall j; \ \sum_i (\epsilon^{do}_j * a_{ij} * X_j) + \sum_c \sum_i (\epsilon^c_j * b^c_{ij} * X_j) + d^{do}_j * X_j = \epsilon^{do}_j * X_j \qquad (3.3)$$

> b^c_{ij} represents the input originating in sector i and country c required to produce one unit output for sector j.
> d^{do} represents the domestic direct fossil energy intensity.
> ϵ^{do}_j represents the domestic embodied energy intensity of sector j and ϵ^c_j the embodied energy intensity of sector j in country c.

In equation (3.3), it is assumed that for each sector imports are proportional to production $(b^c_{ij} * X_j)$.

Ideally, the domestic embodied energy (ϵ^{do}) should be computed by means of equation (3.3), that is by regarding the embodied energy intensities of imports at a country level (ϵ^c). However, the embodied energy intensities of the imports specified by country are generally unknown. Therefore, one often assumes that the EEI of imports are equal to that of domestic products. This assumption results in the following equation:

$$\epsilon^{do} = d^{do} * (I - A - B^{\bullet})^{-1}, \text{ where } B^{\bullet} = \sum_c B^c \qquad (3.4)$$

The embodied energy intensities that can be computed by means of equations (3.3) and (3.4) do not include the capital required to produce these goods and services. According to Casler [1983], ignoring the flow of embodied energy in capital inputs results in significant underestimations of energy intensities because approximately 20% of all energy used in the production processes is consumed in the production of

[5] The matrix of input coefficients (a_{ij}) is calculated by the following equation: $\forall\, i,j;\ a_{ij} = z_{ij} / X_j$

capital goods. Similarly, Wilting [1996] and Noorman [1995] found that neglecting the embodied energy in depreciated capital results in an underestimation of Dutch energy intensities of about 15% for both 1985 and 1987.

There are no detailed data available for the (energy) input of sector *i* in the total consumption of fixed capital in sector *j* (CFC_j). It is assumed that the relative input of sector *i* to the capital consumption of sector *j* (denoted by c_{ij}) is equal to the relative input of the sector *i* to the gross fixed capital formation of the reference year (*i.e.* $GFCF_i / \sum_i GFCF$, where *GFCF* denotes the gross fixed capital formation). The new 'technology' matrix is now obtained by $ac_{ij} = (z_{ij} + c_{ij})/X_j$. In equations (3.3) and (3.4), matrix *A* should thus be replaced by matrix *AC* where capital is included.

The embodied energy intensities can be computed with the resulting technology matrix and the energy intensities involved in the direct consumption of fossil fuel fuels within any particular sector. In making this calculation, one assumes that monetary transactions in the IO-table are proportional to the corresponding physical transactions. Since there are large differences in the purchasing prices of different sectors, this assumption is certainly not valid for deliveries from the energy sectors. To resolve this problem, the use of fossil fuels in terms of primary energy is computed by multiplying the final energy demand per sector per energy carrier by the ERE-value of that energy carrier [Wilting, 1996]. The total ERE-values are computed by multiplying the ERE-values of extraction by those of conversion and transportation. The ERE-values of extraction are assumed to be constant for each country and are derived from Noorman [1995]. The direct fossil energy intensities in the energy sectors are set at zero to avoid double counting [Van Engelenburg *et al.*, 1991; Wilting, 1996; Noorman, 1995].

Eurostat [1992a-e] only presents direct energy use in monetary terms and thus not in physical terms as required in the calculations described above. The energy statistics presented by the OECD [1991a] are used to compute the direct energy use of the 15 sectors for which the direct energy intensities are computed. The sector classification which is presented in Eurostat [1992a-e] is converted to that of the OECD[6] [1991a-b]. The use of two different data sets based on different

[6] The sector classification, with the conversion from the NACE-CLIO group indicated in parentheses, is as follows [van der Linden and Oosterhaven, 1995; Green and le Grontec, 1976]:
1 agriculture, hunting, forestry and fishery [011/030]; 2 Mining and quarrying [120, 131, 132, 133, 140, 151/152]; 3 Food, beverages and tobacco [411, 412, 413 414, 423, 424, 428, 429]; 4 Textile, wearing apparel and leather industries [431/439, 441, 442, 451, 453/456,]; 5 Wood and wood products [461/467]; 6 Paper and paper products [471, 472/473]; 7 Chemical and chemical petroleum, coal, rubber and plastic products [252/259, 260, 481/483]]; 8 Non-metallic products except those from sector 7 [231/239, 241, 242, 243/246, 247, 248]; 9 Basic metal industries [211/221, 222/223, 224]; 10 Fabricated metal products, machinery and equipment [311/316, 321/328, 330, 314/347,

classifications may give rise to errors in the calculations as the sector classifications may involve some inconsistencies. Besides the conversion of the sector classification, the high level of aggregation may also introduce errors in the calculations. The latter problem has been fully addressed in several studies (*e.g.* [Blin and Cohen, 1977; Fisher, 1986; Miller and Blair, 1985]).

3.1.2 Comparison of National Energy Intensities

The embodied energy intensities of France, Germany, Italy, Ireland, The Netherlands, Spain and UK are calculated using equation (3.4). The IO-tables required are taken from Eurostat [1992a-e] and from van der Linden [1999] and Oosterhaven and van der Linden [1995], and the direct energy intensities derived from the statistics of the OECD [1991a]. All calculations are based on the performance of 15 different sectors in 1985, except for The Netherlands, where the calculations are based on 1987 statistics, as Eurostat does not present consistent data for 1985. However, Wilting [1996] shows that the embodied fossil energy intensities did not change much on average at an aggregate level between 1985 and 1987.

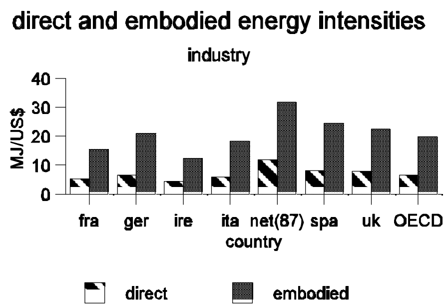

Figure 3.2: The direct and embodied energy intensities for the industrial sector are presented in terms of primary fossil energy use per US$. Data involves the year 1985 except for The Netherlands (1987).

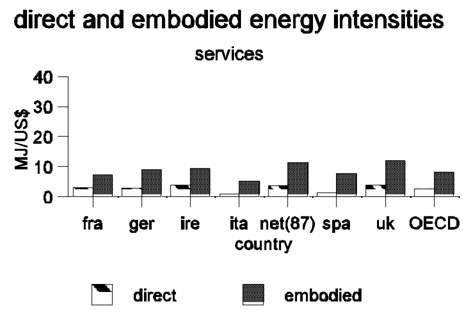

Figure 3.3: The direct and embodied energy intensities for the commercial sector are presented in terms of primary fossil energy use per US$. Data involves the year 1985 except for The Netherlands (1987).

Figures 3.2-3.3 show the direct and the embodied fossil fuel derived energy intensities (or in short the fossil energy intensities) of the sectors services and the industry sector encompassing all industrial sectors. Figures 3.2-3.3 show that both the direct and embodied energy intensities vary from country to country.

351/353, 361/365, 371/374]; 11 Other manufacturing industries [491/495]; 12 Electricity, gas and water [151/152, 161, 162, 163]; 13 Construction [205/509, 620, 671, 672]; 14 Transportation, storage and communication [721/7, 761/764, 771/773, 790]; 15 Services [93a/c, 94a/c 95a/c, 96a/c, 97a/c 660, 710, 830, 840, 850, 99 981/984].

Both figures show the differences in energy intensity in the industrial and the services sector for the various countries within OECD-Europe. The relatively high energy intensity of the Dutch industrial sector is remarkable. The Dutch chemical sector (oil refining included) shows a very high embodied energy intensity of 43 MJ/US$ compared to the average energy intensity of 13 MJ/US$ for OECD-Europe. The energy intensity of the chemical sector raises the direct and embodied average energy intensities of the Dutch industry sector [OECD, 1991a, 1993a]). About 63% of the energy directly used by Dutch industrial sectors is used in the chemical industries. This is more than twice the average share of 30% for OECD-Europe. As might be expected, the direct as well the embodied energy intensity of the commercial sectors is rather low.

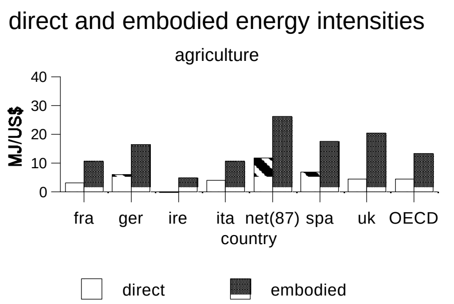

Figure 3.4: The direct and embodied energy intensities for the agricultural sector are presented in terms of the primary fossil energy use per US$. Data involves the year 1985 except for The Netherlands (1987).

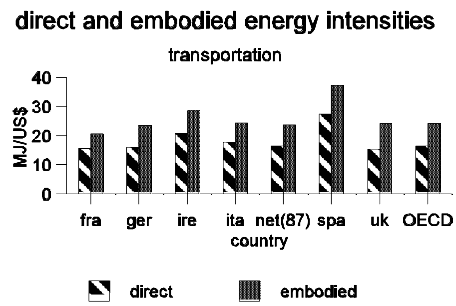

Figure 3.5: The direct and embodied energy intensities for the transportation sector are presented in terms of primary fossil energy use per US$. Data involves the year 1985 except for The Netherlands (1987).

Figures 3.4 and 3.5 show the energy intensities of the agricultural and the transport sector. The relatively high energy intensities of the Dutch industrial and agricultural sector are remarkable. The direct energy intensity of Dutch agriculture is about equal to that of the Dutch industry. This energy intensity reflects the high level of mechanization in Dutch agriculture: The energy use of greenhouses in horticulture and the intensive use of fodder and fertilizers in cattle-breeding (*cf.* Battjes [1993]). For obvious reasons, direct energy intensities constitute a large part of the embodied energy intensities in the transportation sector of each country. Differences between countries are not necessarily the result from structural differences, as the energy use related to private car use is included in the energy statistics of the road transportation sector presented in OECD [20]. To overcome this problem, it is assumed that the use of gasoline and LPG is associated with private car use, while the use of diesel is assigned to public road and freight transportation. In making this distinction, the total amount of energy used for road transportation that is, in fact, used for private transportation can be estimated by combining the statistics of OECD [1991a] and of OECD [1991b].

The energy intensities presented above also include imports. The latter is computed under the assumption commonly used that the EEI of imports equal that of domestic products. However, the figures shown above indicate clearly that this assumption is generally not valid. For instance in case of the Netherlands this assumption will most likely result in an overestimation of the EEI of imports. Hence, computing the EEI of imports by using average values of domestically produced goods and services may introduce errors.

Foreign trade is illustrated in figure 3.6. In this figure, arrows indicate trade relations among three countries, together forming one region. Imports include trade from countries within OECD-Europe (grey arrows of figure 3.6) as well as trade from countries outside OECD-Europe (black arrows of figure 3.6). Ideally, the embodied energy intensities of all imports are computed by taking into account the energy intensities for each country of origin. This exercise requires an interregional input-output table in which data on the intermediate deliveries from each sector of a country to the sector of any other country (*i.e.* outside as well as within the region) are available. Such an interregional input-output table is not yet available for OECD-Europe.

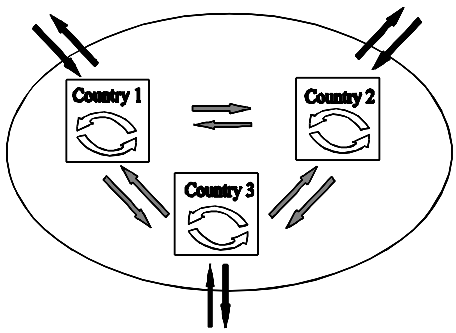

Figure 3.6: Schematic overview of trade among countries within one region. The grey and black arrows represent foreign trade with countries inside and outside the region, respectively. The white arrows indicate domestic trade. The outer ellipse represents the boundary of the region.

Sections 3.2 and 3.3 present different estimation procedures for a number of countries within OECD-Europe. These procedures should be regarded as a first step in computing the EEI of imports more accurately. Two additional approaches (denoted by ‘OECD’ and ‘Region’) to assess the EEI of imports are introduced below and are compared with the approach commonly used (denoted by ‘domestic’). In the first (single region) approach (‘OECD’), the EEI of imports are assumed to be equal to the average value of OECD-Europe. In the second (multi-regional) approach (‘Region’), the EEI of imports originating within OECD-Europe (grey arrows of figure 3.6) are determined by considering the energy intensities of the subregion. In addition, the EEI of the other imports (black arrows of figure 3.6) are assumed equal to average value of OECD-Europe. In the three approaches presented, all calculations are performed at a level of 15 sectors.

3.2 A Second Single Region Approach for Assessing Energy Intensities of Imports

Taking into account the prominent role of imported goods and services, the question arises whether the use of the EEI of the aggregated OECD-Europe region (see figure 3.6) leads to a more accurate estimate of the EEI of imports of an OECD-Europe member state than the use of domestic energy intensities alone would provide. The latter assumes that the EEI of imports are equal to the EEI of the domestic country and it is introduced in section 3.1 (see equation (3.4)). The former assumes that the EEI of imports are equal to the average values of OECD-Europe and this approach is outlined in this section.

3.2.1 Methodology of the single region approach of OECD-Europe

As mentioned above, the first single region approach involves the assumption that the energy intensities of imports are equal to that of domestically produced goods and services (which holds that $\epsilon^c_j = \epsilon^{do}_j$ for each country see equations (3.3) and (3.4)). In the second option, the EEI of the imports for each country (ϵ^c_j in equation (3.3)) are assumed to be equal to an average value that is calculated for the aggregated region (in this case study the relevant region is OECD-Europe and this option is, therefore, denoted by 'OECD'). Equation (3.5) results from equation (3.3) (which holds that $\epsilon^c_j = \epsilon^{OECD}_j$ for each country *c*).

$$\epsilon^{do} = d^{do} * (I - AC)^{-1} + \epsilon^{OECD} * B^{\bullet} * (I - AC)^{-1} \qquad (3.5)$$

As mentioned before, imports include trade from countries within OECD-Europe (grey arrows of figure 3.6) as well as trade from countries outside OECD-Europe (black arrows of figure 3.6). Lack of data concerning imports from certain countries within OECD-Europe as well as from countries outside OECD-Europe influences the construction of equation (3.5). Similar to the adjustments related to equation (3.4), the technology matrix *AC* of equation (3.5) represents the technology matrix adjusted for capital.

An IO-table of OECD-Europe is required in order to compute the Leontief inverse of equation (3.5). Such a table is not yet available. Therefore, the technology matrix is estimated by using the consolidated IO-table of a number of countries in the European Union as a starting point [Van der Linden and Oosterhaven , 1995]. The so-called RAS-method is used as the estimating procedure [Bacharach, 1970; Miller and Blair, 1985]. The technology matrix of OECD-Europe is determined by the following equation:

$$(AC + B^{\bullet})^{OECD} = R * (AC^0 + B^{\bullet 0}) * S \qquad (3.6)$$

Matrix $(AC^{0} + B^{\bullet 0})$ represents the technology matrix used as starting point (see above), where AC^{o} and $B^{\bullet 0}$ represent the cost incurred per unit output by both domestically produced and imported goods and services (capital included). Both (diagonalised) matrices R and S are computed iteratively and are the result of successively adjusting the row and columns of matrix $(AC + B^{\bullet})$ until the row and column totals of the matrix $Z = (AC + B^{\bullet}) * X^{OECD}$ finally approximate the observed row and column totals of OECD-Europe. For a detailed outline of the RAS-procedure, see Bacharach [1970] and Miller and Blair [1985]. By following this method, it is assumed that the technology matrix of OECD-Europe deviates minimally from the technology matrix derived from the consolidated IO-table of the EC (presented by Van der Linden and Oosterhaven [1995]).

The use of the RAS-method for estimating the input-output table of OECD-Europe introduces errors in the energy intensities. Although the row and column totals of the estimated *Z*-matrix approximate the original row and column totals, the elements of the estimated *Z*-matrix can deviate considerably from the target matrix of intermediate deliveries. This problem is also addressed in Miller and Blair [1985]. They present a case study in which the elements of an estimated Z-matrix deviate strongly from the target matrix of intermediate deliveries. However, these large errors appear to have much less impact on the Leontief inverse associated with this matrix, a consequence which is of more concern in our case.

3.2.2 Assumptions

The row and column totals which are required to carry out the RAS-method are computed by using the data of total production, imports, final demand and value added. The required data are not available for all countries of OECD-Europe. Therefore, a number of assumptions are made in order to estimate the input-output table of OECD-Europe. These assumptions are listed below.

- The production figures are derived from the statistics provided by the UN [1991], OECD [1995] and Eurostat [1992a-e]. Production data for Belgium and Luxembourg were estimated by using the average ratio between the value added and the production in the same sector of other OECD-countries. The same method is applied to a number of sectors of Greece (sector 1, 13-15), Portugal (sector 2) and Turkey (sector 1, 2, 13-15).
- For each country, the totals of final consumption expenditure of both households and governments (PC and GC), gross fixed capital formation (GFCF) and changes in stocks (ChSt) are derived from OECD statistics [OECD, 1993a]. The final demand of OECD-Europe is computed by converting all data into (1985)US$ (World Tables [1992]). For most countries, the sectors of origin are not known for the final demand. The column of change in stocks (ChSt) is added to the column of final consumption expenditure (PC and GC). The RAS-method is now applied to the *Z*-matrix ($(AC + B^{\bullet})^{OECD} * X^{OECD}$) and to the two final demand columns (final

consumption expenditure & changes in stocks and gross fixed capital formation). A separate treatment of exports to countries outside OECD-Europe and which are also part of the final demand is described below:

! The total export of each sector is determined by using the foreign trade statistics of commodities provided by the OECD [1992]. For the purpose of this study, each commodity is allocated to its sector of origin. Trade in commodities does not involve trade in services, transportation and construction. It is, therefore, assumed that the transportation, services and construction sectors of OECD-Europe are not exporting to the rest of the world. Note that only exports to countries outside OECD-Europe are taken into account (the black arrows of figure 3.6) as the intra-regional trade (grey as well as white arrows in figure 3.6) are considered to be 'domestic' intermediate deliveries. Another problem concerning the trade statistics concerns the internal consistency of import data: for instance, imports into country A from country B that are given by country A not always match the export figures (from country B to country A) presented by country B. Boomsma *et al.* [1991] state that these inconsistencies are often caused by the differences in the valuation of the imports and exports. These inconsistences may take place for a variety of reasons.

! Data on value added per sector are derived from statistics provided by the OECD [1993a], the UN [1991] and Eurostat [1991a-e]. The value added figures contained in these sources deviate slightly for a number of sectors.

! Although total imports are included in the matrix of intermediate deliveries, imports specified by the sector of origin are required to compute the total resources (i.e. domestic production and imports). These imports should only involve the imports from outside OECD-Europe, since the intra OECD-European trade should be regarded as domestic trade (In figure 3.6 this trade is represented by the grey arrows). The import statistics are derived from the statistics on the foreign trade of commodities (OECD [1992]). They do not cover construction, transportation and services. Therefore, it is assumed that there are no imports from the transportation, services and construction sectors from outside OECD-Europe. Note that exports from these sectors are also not covered.

With the data obtained above, it is possible to estimate the technology matrix of OECD-Europe at a level of 15 sectors. The technology matrix and the relative share of the deliveries from the sectors of origin to the two final demand columns in the consolidated IO-table of the EC [Van der Linden and Oosterhaven 1995; van der Linden, 1999] are used as a starting point. The RAS-method has been applied to estimate the *Z*-matrix and the two final demand columns. The first final demand column includes private consumption (PC), governmental consumption (GC) and changes in stocks (ChSt) The second column comprises gross fixed capital formation (GFCF). In order to execute the RAS-method, the total inputs should by definition be equal to the total outputs. This need not be the case here because the totals are derived from various sources and not from one IO-table. These two totals deviate about 2% in the case of OECD-Europe, and therefore the output totals are adjusted in order to satisfy equation (3.4) or (3.6).

Capital depreciation is internalised after executing the RAS-procedure because the column of gross fixed capital formation should first be computed first. Data on capital depreciation per sector are scarce and are computed by using the total consumption of fixed capital as presented by OECD [1993a] and the distribution patterns derived from statistics of the OECD [1995]. These distribution patterns are based on capital depreciation data computed by using the data of total fixed capital and of lifetime (although the computed totals of capital depreciation may not correspond to the totals presented by OECD [1993a]).

3.2.3 Results

The impact of different assumptions regarding the EEI-of imports is studied by comparing the German, the Dutch, and the Irish EEI. The energy intensities are calculated in the usual way (assuming that the energy intensities of imports are equal to the domestic EEI), with the EEI calculated by using the average intensities of OECD-Europe to estimate the energy intensities of imports. The German embodied energy intensities are about equal to the OECD-Europe average while the Dutch and Irish embodied energy intensities are respectively higher and lower than the average values of OECD-Europe. Figure 3.7 shows the results. From figure 3.7, it can be concluded that estimating the EEI of imports using the average EEI of OECD-Europe (option 'OECD') instead of the domestic EEI (option 'domestic') has a large impact (up to about 20%) on the calculation of embodied energy intensities. As might be expected, the assumption that the EEI of imports is equal to that of domestically produced goods and services results in an overestimation of the embodied energy intensities in The Netherlands and an underestimation for Ireland. This certainly applies to the industrial and agricultural sectors of both countries. Not only is this the result of differences in EEI but also of the large contribution of imports to the total resource of both countries: 20% in The Netherlands and 23% in

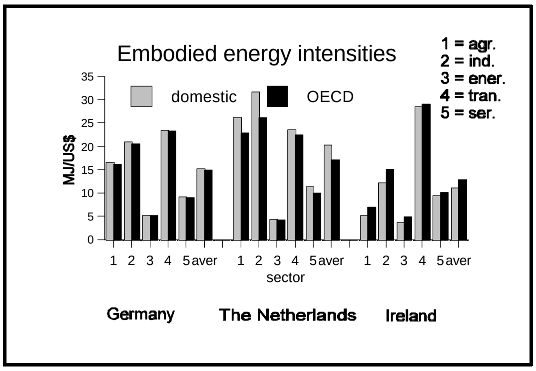

Figure 3.7: The embodied energy intensities for five aggregated sectors and the average value for Germany, The Netherlands and Ireland in MJ/US$. 'Domestic' and 'OECD' represent the assumptions that the EEI of imports are equal to the domestic EEI and the average EEI of OECD-Europe, respectively.

Ireland (OECD [1991c]). For Germany, the method of calculation (option 'domestic' versus 'OECD') appears to have only a small affect on the outcome. This is not surprising, since the domestic EEI of Germany are about equal to the EEI of OECD-Europe except in a number of industrial sectors. Furthermore, imports only comprise about 13% of the total resources of Germany.

Using the average values of the OECD seems a first step in avoiding errors in assessing the EEI of imports. A next step to avoid these errors is to take into account regional differences within the OECD-Europe region by specifying the trade among European OECD-countries (or subregion) of origin (grey arrows of figure 3.6). This multi-regional approach and is outlined in section 3.3

3.3 Multi-Regional Approach

3.3.1 Methodology of the Multi-Regional Approach

For each region, data on the average embodied energy intensities and trade flows are required to specify imports to the country (or subregion) of origin within OECD-Europe. The EEI of imports can then be computed by using the so-called multi-regional approach that estimates an inter-regional IO-table by combining technology data at a country level with the corresponding trade statistics. Ideally, the calculations of this regional approach are performed at a country level. Such an exercise requires that input-output tables are available for each country of OECD-Europe. However, consistent IO-tables are only available for several countries [Eurostat, 1992a-e]. Moreover, OECD-Europe consists of 19 countries and considering all these countries separately results in too large and complex matrices. Hence, the countries of OECD-Europe are grouped into subregions in which at least the most countries of OECD-Europe with the most dominant economies (*i.e*. France, Germany, Italy and UK) are considered separately. The region classification is presented in table 3.1. So at least, the regional differences in the most dominant economies are taken into account. Grouping the other countries into a region is not trivial since there are no obvious criteria for making clear region classification. Hence, the region classification that is introduced here may seem somewhat arbitrary. However, it is assumed that considering the most dominant countries separately is the most important step in computing the embodied energy intensities at a regional level. Countries are grouped together into one (sub)region based on similarities in their fuel mix and on the additional requirement that countries within a region should be adjacent or near by. Similarity in fuel mix is mainly based on the contribution of fossil fuels to the total direct fuel use and the fossil fuel mix and nuclear fuels for the electricity generation. Similarities in economic structure are assumed to be reflected in the GDP per capita and the contribution of the different sectors to the total GDP. However the similarity in economic structure only played a minor role in the regional classification. In order to investigate the impact of region determining classifications on assessing the embodied energy intensities, a case study was carried in which Switzerland was shifted from region 3 into region 4. This shift hardly affected the embodied energy intensities of boh regions 3 and 4.

Table 3.1: Region classification

Region 1	UK and Ireland
Region 2	Denmark, Finland, Iceland, Norway, and Sweden
Region 3	Austria, Germany and the Netherlands
Region 4	Belgium, France, Luxembourg, and Switzerland
Region 5	Spain and Portugal
Region 6	Greece, Italy and Turkey

Let z^{rs}_i denote the deliveries of goods and services from sector *i* of region *r* to region *s*, irrespective of its destination. These deliveries will find their destination in the producing sectors of region *s* as well as in the final demand of region *s*. Let $z^{\bullet s}_i$ $(= \sum_r z^{rs}_i)$ represent the total of deliveries of *i* to region *s*. When each element z^{rs}_i is divided by $z^{\bullet s}_i$ one obtains the proportion of the products used in region *s* that is produced in region *r*. This coefficient is denoted by tr^{rs}_i (thus $tr^{rs}_i = z^{rs}_i / z^{\bullet s}_i$).
The embodied energy intensities can now be computed as follows (equation (3.7)):

$$\forall\, j,s{:}\ \epsilon^s_j = d^s_j + \sum_{r,i} (\epsilon^r_i * tr^{rs}_i * AC^r_{ij}) \qquad (3.7)$$

In equation (3.7), AC^r represents the technology matrix of region *r* adjusted to inputs which includes the consumption of capital. The matrices AC^r_{ij} are not available at a regional level and therefore these matrices are estimated. The estimation methodology used is similar to that of the whole region of OECD Europe. That is, the RAS-method is used to assess the technology matrix for each region (see section 3.2.1). Data sources and the assumptions involved in this procedure are also similar to the sources and assumptions listed in section 3.2.2, as otherwise both the single region and the multi-regional approach would not be comparable. Hence, trade statistics to develop matrix tr^{rs} are also derived from [OECD, 1992].

3.3.2 Results

Following the considerations above, OECD-Europe has been divided into 6 regions and the non-European OECD-countries are lumped together in one large region (*i.e.* the rest of the world). The multi-regional input-output table derived this way facilitates a more accurate assessment of the embodied energy intensities of imports. Figure 3.8 clearly shows that the regional approach (this option is denoted by 'region') influences (although less clearly) the total embodied energy intensities observed for the aggregate sectors of Ireland, The Netherlands and Germany (note that figure 3.8 is similar to figure 3.7 only it includes the option 'region'). Apparently, assessing the imports with the aid of the average energy intensities of OECD-Europa appears to be a useful first step to calculate the EEI of imports. However, it should be noted that the EEI of imports of non-European OECD-countries are still assessed by using the average values of OECD-Europe. The results presented in figure 3.8 (and 3.7) do not show striking differences. The figures presented involve the embodied energy intensities and, therefore, direct energy is included. The direct energy input is equal in all three options. Only EEI of the inputs of goods and services (domestically produced goods as well as imported) differ among the options (*i.e.* intermediate domestic deliveries and imports).

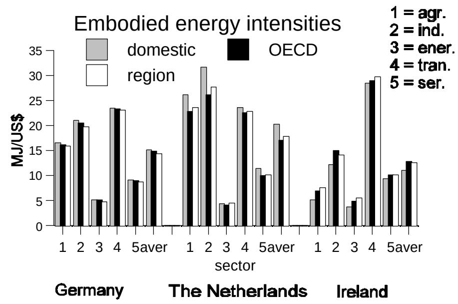

Figure 3.8: The embodied energy intensities for 5 aggregated sectors and the average value for Germany, The Netherlands and Ireland in MJ/US$. 'Region denotes the results of the regional approach to compute the EEI of imports. 'Domestic' and 'OECD' represent the assumptions that the EEI of imports are equal to the domestic EEI and the average EEI of OECD-Europe, respectively

3.4 Energy Flows in OECD-Europe

Not only can the energy intensities be computed more accurately by means of this multi-regional input-output table but the energy flows among regions can be determined too. Studying these energy flows in a dynamic way is one of the major objectives of the ECCO-modelling approach. The (embodied) energy flows among the 6 defined European regions are presented in figure 3.9. In this figure, the width of the arrows indicates the magnitude of the embodied energy flows. Circle arrows represent the intermediate deliveries of a region (note that these intermediate deliveries include trade among the countries within the subregion).

Figure 3.9 shows that the regions 3, 4, 5, and 6 have a negative import-export balance which means that these regions depend heavily on energy resources outside the region. Notably for region 4 and 6, the net (embodied) energy imports comprise a relatively large part of the total energy flows within these regions. Region 1 and 2 appear to be more self sufficient and both regions are even net (embodied) energy exporting regions. However, the aggregate OECD-Europe region is in terms of embodied energy a net importing region: net imports are about 21 EJ compared to 'domestic' intermediate deliveries of about 75 EJ in 1985. The relatively high magnitude of imports originating from non-European OECD-regions is due to the enormous contribution (between 85-95% for all regions) of fossil fuels to these imports, that is the energy carriers themselves (*e.g.* crude oil).

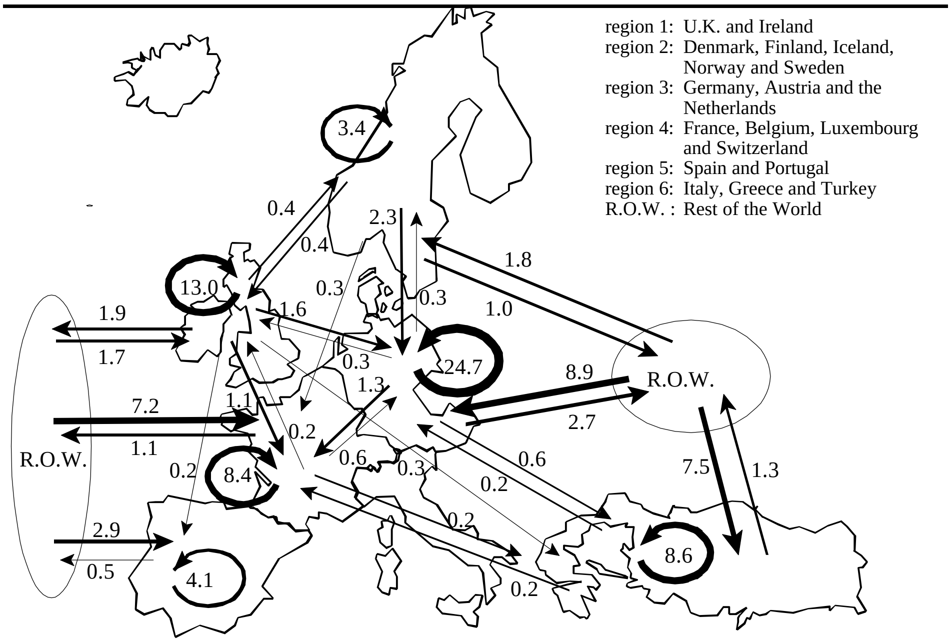

Figure 3.9: Overview of embodied energy flows (in EJ) in 1985 in OECD-Europe. Flows less than 0.1 EJ are not shown.

Another remarkable difference between the regions is the magnitude of the embodied energy flows. The energy content of intermediate deliveries of region 3 (24.7 EJ) is by far the largest of OECD-Europe and is about three times as high as that of region 4, although the total production of region 3 is less than twice the production value of region 4 (about 1900 billion US$ for region 3 compared to 1200 billion US$ for region 4 and 800 billion US$ for region 1). The relatively low value of region 4 can be explained by the fact that the electricity supply in region 4 depends heavily on nuclear energy (about 60% [OECD, 1991a]) and nuclear energy is not included in these calculations. Electricity is generated mostly from coal in both region 1 and 3 (58% and 55%, respectively) in 1985 (note that former East Germany is also included in region 3 for the year 1985). Region 2 being the smallest region of OECD-Europe, in terms of population and its total production being relatively low too (expressed in monetary terms, total production equals 455 billion US$), supports the low value of the intermediate deliveries of this region. Moreover, the electricity generation depends for about 85% [OECD, 1991a] on non-fossil fuels. The relatively low energy content observed for region 5 and 6 can partly be justified by the relatively low production level (about 365 and 945 billion US$, respectively) and for region 5 also by the electricity generation as in region 5 non-fossil fuels contribute for about 50% to electricity production.

Naturally the flows presented in figure 3.9 have static character. The dynamics of these flows can be studied by means of the regional ECCO-model or regional DREAM-model of OECD-Europe which is described in the next chapter. In this chapter, the energy flows of figure 3.9 and the input-output tables presented above are used as staring point.

3.5 Conclusions and Discussion

There are large national differences in embodied energy intensities. For example, the direct and the embodied energy intensities of the Netherlands and Ireland differ substantially from the average values of OECD-Europe. This may be due to rather specific economic structures and the contribution of imports to the total resources. For example, the oil refining industry has a large impact on the Dutch (chemical) industry sector and imports comprises 20% of the total resources in the Netherlands.

The usual assumption that the embodied energy intensities (EEI) of imports can be calculated in terms of the domestic EEI introduces errors in the calculation of the EEI for a country. These errors may be substantial for countries with a relatively high contribution of imports and a rather specific economic structure. Hence, two other approaches are introduced to avoid these errors. It has been demonstrated that the EEI of imports can be based on the average EEI of OECD-Europe. Moreover, the EEI of imports can also be determined by specifying the imports in terms of their origin (*i.e.* by dividing OECD-Europe in 6 subregions). It is believed here that avoiding these errors in the calculations by using the two approaches introduced above results in more accurate assessments of the energy intensities. However, it should be noted that all calculations were performed at a level of 15 sectors which might exaggerate somewhat the results compared to involving more sectors.

A next step in avoiding errors in assessing the EEI of imports consists of specifying the imports in terms of their origin: the OECD-Europe versus the non-European OECD-countries and the rest of the world. This alternative requires the availability of average embodied energy intensities data for each region.

The energy flows among the regions are very region specific and given the total output in terms of money in these flows illustrate the energy intensiveness of the production of the various regions. Especially, regions 2 and 3 appear to be rather energy intensive which can be ascribed largely to the fuel mix in the electricity production sector.